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# SIRIUS PRE-ALIGNMENT RESULTS

R. Junqueira Leão, G. Rovigatti de Oliveira, H. Geraissate Paranhos de Oliveira,
U. R. Sposito, F. Rodrigues,
Brazilian Synchrotron Light Laboratory, Campinas, Brazil



*Abstract*

Sirius is a 4th generation synchrotron light source under final installation and beginning of commissioning phase in Brazil, with a bare emittance of 250 picometer rad. In order to fulfil stability requirements (maximum magnets displacement of 6 nm caused by vibration) imposed to achieve expected performance, the mechanical assembly of supporting structures and magnets were designed without adjustment mechanisms. Yet, the misalignment errors of the magnets are the dominating source of dynamical aperture reduction, leading to a maximum permissible deviation of 40 micrometers between adjacent magnets. To this end, dimensional engineering was applied to conceive an alignment concept for magnets on a same girder based solely on the geometric characteristics of the parts. For the large volume positioning of girders in the storage ring tunnel, the applied methodology followed a strategy optimized to reduce measurement uncertainty, as described in the literature. This paper will present the complete measurement process that led to the pre-alignment of Sirius, from the deployment and survey of reference networks to planning future fine alignment of the machine. To express a consistent and unequivocal alignment result and assess the alignment quality considering the measurement uncertainty, an innovative metric described previously was employed. This work will show that the positioning of girders satisfies the requirement of 80 micrometer. Also, the devices and mechanisms used for assembling will be detailed. Inspection of full girder set performed on a Coordinate measuring machine shows a maximum deviation of 30 micrometers for any pair of magnets on a common girder.

## INTRODUCTION

In the campus of the Brazilian Center for Energy and Materials – CNPEM, in the Brazilian city of Campinas, there is a large effort in the development of a fourth-generation light source, called Sirius. This synchrotron is in the installation and commissioning phase, with first beam in the storage ring intended for late this year [1].

The requirements in terms of alignment [2] are compatible with the current state-of-the-art 3D measurement techniques and portable instruments such as laser trackers. However, the demands with respect to stability [2] means that the fewer adjustment devices and movable parts, the better. To this end, the alignment design was broken down to two different approaches.

The inter-girder alignment uses traditional metrology-assisted positioning, whereas the intra-girder alignment makes intensive use of design choices to achieve a relative positioning based solely on simple tooling. This paper will present these solutions and the preliminary results of alignment activities and validation experiments.

## ALIGNMENT DEVELOPMENT

The alignment tolerances for Sirius are 0.160 mm for the Booster magnets and 0.080 mm for the Storage Ring girders. For the Storage Ring magnets, a tighter tolerance of 0.040 mm is required [2].

### *Infrastructure*

The reference network was adjusted after a preliminary network installed and surveyed in the Experimental Hall (average point uncertainty of 0.250 mm, 150 points) and a local network was installed and measured inside the Linac tunnel (average point uncertainty of 0.150 mm, 70 points). The Storage Ring network was then measured and connected to the previous networks. It has approximately 1200 points, with an uncertainty of 0.106 mm (uncertainties estimated using a confidence interval of 95 %). Both the design and the surveying procedure of this network intend to reduce measurement uncertainty [3].

### *Linac*

The complete Linear Accelerator was manufactured by the Shanghai Synchrotron Radiation Facility – SSRF and its alignment was conducted in cooperation with their technical team. It consisted in guiding the magnets fiducials to their designated position, with the help of laser trackers, followed by a straightening process of the accelerating tubes. This operation employed measuring arms and iterative adjustment cycles. At last, a refinement (often called smoothing [4]) process was applied, in which the position of the fiducials was better estimated through the Unified Spatial Metrology Network – USMN algorithm [5]. The alignment took one month, and the result was better than 0.3 mm for all its components.

### *Booster*

As-built measurements have shown deviations in the order of 10 to 20 mm in the walls of the radiation shielding, where the Booster is supported. Although these deviations are quite small for civil construction, they would be large enough to jeopardize the horizontal alignment mechanisms designed for the Booster pedestals. Therefore, the first step in aligning the Booster was to measure all the fixation points and shim them all. This would pre-align all the supports and consequently the range for fine alignment purposes in all the components would be preserved.

The next step was to pre-align the Booster. Special target holders were devised to materialize the corners of the magnet yokes, which were put in their nominal coordinates.

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The booster pre-alignment took about three months, with a full-time laser tracker and two metrologists, plus occasional part-time laser tracker and another two metrologists. Frequently, another Tracker and members helped them on the same job, in order to enable the Vacuum team working on Booster. The goal of the pre-alignment was to allow the installation of vacuum components. At the time of this activity (second trimester of 2018), the tunnel was not temperature controlled, however the average environmental temperature was close to the nominal operation temperature of 24 ºC. Figure 1 shows the results of a recent verification campaign on the Booster.

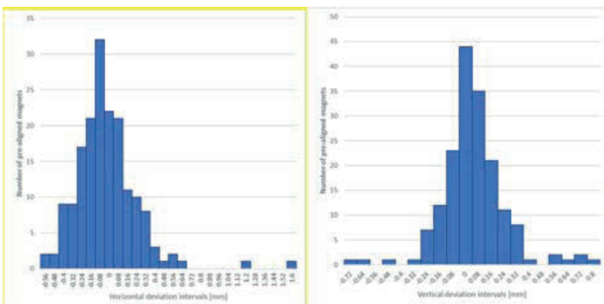

Figure 1: Histograms of the deviations for the Booster.

Approximately 62% of the Booster magnets are within 0.160 mm of their nominal positions in horizontal. In the vertical direction this number is about 78%.

### *Storage Ring*

Similarly to the Booster, the aim was to assembly the supporting structures in such a way that the range of the adjustment mechanisms would be maximized. In the case of the Storage Ring this was a major issue, since this accelerator is installed on the floor and the range of the levelling units is only 5 mm in order to improve the stability of the structure. The peak to valley largest deviation of the slab is only about 23 mm for the whole special slab of accelerators and experimental hall (this measure includes flatness and level). The supporting structure of the Storage Ring consists of a concrete base, rigidly grouted to the slab, followed by a metallic wedge, levelling mechanisms and girders. All contact points between the concrete bases and the slab were measured and shimmed. This approach assured a pre-levelling of the supporting structure in the order of a few hundredths of millimeters.

In order to orientate the pre-alignment, the limiting magnets corners of each girder were used. Again, special target holders were employed. Figure 2 depicts a full sector of the Storage Ring and a section of the Booster.

Figure 2: Picture of a complete sector.

The whole procedure took about four months to complete with two dedicated laser trackers and two personnel. Fig. 3 presents the results for the Storage Ring.

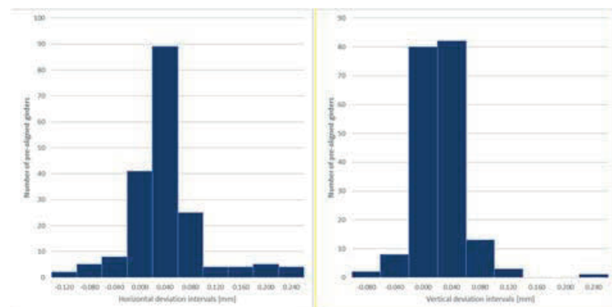

Figure 3: Histograms of the deviations for the Booster.

In horizontal, approximately 89% of the girders are within 0.080 mm while in vertical this index is already 98%.

### *Magnets Centerlines Measurement Validation*

The intra-girder alignment (relative alignment of the magnets of a common support) was achieved without adjustment mechanisms. This approach benefits from the point-of-view of higher natural frequencies, caused by the lack of weak links represented by screws and levelling units between magnets and girders. This new strategy meant no fiducials were needed on the magnets, and that the positioning would be the result of the geometric characteristics of the parts. Through the intensive use of Dimensional Engineering and precision machining, simple fixtures were used to assembly the girder sets. However promising, these results should be reproducible with portable instruments at the tunnel. A special laser tracker measuring routine was then developed, in which the four corners of each magnet are measured and only the frontal face of each magnet is measured.

By estimating the centerlines of the magnets and fitting the same cylinder evaluated on the CMM, the results have shown that the accuracy of the technique is below 0.010 mm. The experiment was conducted from different orientations of the laser tracker. Figure 4 shows this setup. The diameter of the cylinder varied between 0.045 mm and 0.054 mm for all the experiments. The conclusion is that the maximum deviation between any pair of magnets in the same girder do not exceed ± 0.030 mm. It is a remarkable

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result, considering the tolerance of ± 0.040 mm between adjacent magnets.


Figure 4: Girder set measured by a CMM (left) and by a laser tracker (right).

With a proper uncertainty evaluation of the points and a sensible propagation of uncertainty from the reference network, the cylinders representing the alignment deviations inside each girder in the Storage Ring will allow the use of a robust metric for the alignment quality, in an extended rationale demonstrated in previous work [6].

### *Fine Alignment Strategy*

For the fine alignment, planned to take place after the environmental control of the tunnel and before the commissioning phase, the multipole girders will be aligned prioritizing the quadrupoles whenever possible, due to its larger impact on the optics of the machine if compared to the sextupoles. For the different dipole girders, however, the fine alignment procedure will need to simulate what has been measured during magnetic characterization. The impact of this approach is that each degree-of-freedom of the assembly will have different features to be used as references. For example, in the case of a pure dipole girder, the level will be adjusted by measuring the top of the girder, while the yaw angle will reference the lateral rail of the girder. Also, manufacturing specificities of the dipole yoke will demand that transversal and longitudinal adjustments, as well as the height will be based on the central segment of the dipole.

## DISCUSSION AND CONCLUSIONS

The results presented the absolute deviations between nominal and real positions of the magnets and girders. A different analysis can be performed by looking at how continuous is the electrons trajectory formed by the magnets. This is especially relevant since the temperature inside the tunnel is not yet stable, and some sectors of the machines can still be deformed by differential dilatation. Also, some portions of the machine, especially the Booster, are already affected by this problem, which can be noticed by the outliers presented in the histograms of Fig. 1.

Figure 5 shows a plot of the deviations of the magnets and girders and a derivative function of these deviations with respect to their longitudinal position on the machine.

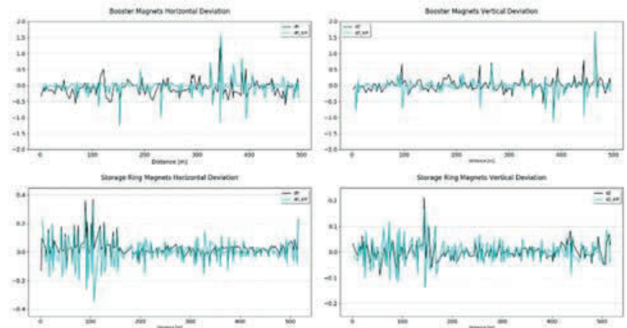

Figure 5: Derivatives of the magnets and girders deviations for the Booster (top) and Storage Ring (bottom).

With this analysis, it is possible to consider whether to realign specific magnets or girders. Due to the relatively large distances between the magnets on the machine, the trajectory fitted by the magnets could be sufficiently continuous not to justify any realignments before the HVAC subsystem is fully operational. In this case, however, one notice that for most part of the trajectory for the Booster (both horizontal and vertical), the deviations are smooth to less than 0.25 mm per meter. However, specific cases where there are neighbor magnets close to each other and large deviations, there is a peak in the derivative functions. For these cases, immediate action will be needed. For the Storage Ring, these numbers are in the order of 0.100 mm per meter for most cases.

## REFERENCES

[1] L. Liu et al., "Sirius Status Update", presented at the 10th Int. Particle Accelerator *Conf. IPAC'19*, Melbourne, Australia, May 2019, paper TUPGW003, this conference.

[2] https://wiki-sirius.lnls.br/

[3] R. Junqueira Leão et al., "Engineering survey planning for the alignment of a particle accelerator: part II. Design of a reference network and measurement strategy", *Meas. Sci. Technol.*, 29 034007

[4] H. Friedsam and W. Oren, "The application of the principal curve analysis technique to smooth beam lines", *in Proc. 1st International Workshop on Accelerator Alignment*, SLAC, American, May 1989, pp. 51-54.

[5] J. Calkins, "Quantifying Coordinate Uncertainty Fields in Coupled Spatial Measurement systems", Ph.D. thesis, Mech. Eng. Dept., Virginia Tech, Virginia, United States, 2002.

[6] R. Junqueira Leão et al., "Engineering survey planning for the alignment of a particle accelerator: part I. Proposition of an assessment method", *Meas. Sci. Technol.*, 29 034006